An AERIS Data Environment Based On Existing Systems Development

FINAL REPORT

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16. Abstract

The AERIS (Applications for the Environment: Real-Time Information Synthesis) Program was initiated to generate or acquire environmentally relevant real-time data to create actionable information that will support and facilitate "green" transportation choices by system users and operators. This project is one of several awarded by the Federal Highway Administration (FHWA) in 2010 under a Broad Agency Announcement (BAA).

The purpose of this project is to examine the relevance of FHWA's Clarus and MDOT's Data Use Analysis and Processing (DUAP) data, and their core system designs, to the needs of the AERIS Program, and to recommend a Preliminary System Development Plan for an AERIS data environment.

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Table of Contents

1 Introduction 6
2 PROJECT OVERVIEW 6
3 BACKGROUND 7
3.1 The Clarus System 8
3.2 The DUAP System 10
4 DEVELOPING AN AERIS DATA ENVIRONMENT 12
5 THE SYSTEMS DEVELOPMENT PROCESS 12
6 ENVIRONMENTAL DATA IN *CLARUS* AND DUAP 14
7 GATHERING PRELIMINARY USER NEEDS 17
8 EXAMPLE ANALYSIS OF DATA REQUIREMENTS 20
8.1 The MOVES Model 20
8.2 The VISSIM Model 22
8.3 Other Models 23
9 PRELIMINARY SYSTEM DEVELOPMENT PLAN 24
9.1 System Concepts and User Needs 24
9.2 Requirements 25
9.3 System Design 25
9.4 System Development Needs 27
9.4.1 Core Data Management Functions 27
9.4.2 Data Collection 27
9.4.3 Data Quality Checking and Pseudo-observation Derivations 27
9.4.4 Data Presentation and Distribution 29
9.5 Testing and Applications Assessment 29
APPENDIX A - Deinitions, Acronyms, and Abbreviations 31
10 Appendix B – Data elements in the *Clarus* and DUAP systems 32
11 Appendix C – ANALYSIS of C*larus* and *DUAP* data in MOVES and VISSIM 38

1 Introduction

The AERIS (Applications for the Environment: Real-Time Information Synthesis) Program was initiated to generate or acquire environmentally relevant real-time data to create actionable information that will support and facilitate “green” transportation choices by system users and operators. This project is one of several awarded by the Federal Highway Administration (FHWA) in 2010 under a Broad Agency Announcement (BAA).

Mixon Hill was joined in this work by the Texas Transportation Institute (TTI), and called on the Michigan Department of Transportation (MDOT) and the Mid-America Regional Council (MARC), the metropolitan planning organization for the bi-state Kansas City region, as public agency advisors.

2 PROJECT OVERVIEW

The purpose of this project is to examine the relevance of FHWA’s Clarus and MDOT’s Data Use Analysis and Processing (DUAP) data, and their core system designs, to the needs of the AERIS Program, and to recommend a Preliminary System Development Plan for an AERIS data environment.

Clarus and DUAP represent state-of-the-art data acquisition tools. The Clarus system emphasizes data collection from fixed environmental sensor stations (ESS) but is currently being enhanced to incorporate data from mobile sources, such as snow plows. DUAP focuses on the collection of data from mobile sources, particularly connected vehicle fleets, but also acquires data from fixed roadway traffic sensors. Between the two systems, sophisticated real-time data quality checking algorithms have been implemented; techniques for integrating data from multiple disparate sources have been developed; real-time data visualization tools have been created; and applications that translate raw data into actionable information for the benefit of system users have been designed and implemented.

Since the Clarus and DUAP systems are operational and significant investment has already been made, the intent of this project is to determine how FHWA can leverage these assets and leapfrog some of the normal system development cycle. This report covers the following material to arrive at a recommended Preliminary System Development Plan.

First, the Clarus and DUAP systems are described in sufficient detail to provide information on their background and development history, how they function and what they include, covering data acquisition, quality checking algorithms, data storage, processing, and applications where applicable.

The report then identifies the need for an external AERIS data environment that could acquire, quality check, store, and process environmental and related data sets for AERIS user applications and for data sharing with other data capture and management systems, such as U.S. DOT’s proposed Research Data Exchange (RDE) within the Data Capture and Management (DCM) Program.

This is followed by a discussion of the systems development process, including the process for understanding the needs of stakeholders and users in conceptualizing a system, the systems engineering process that was used for *Clarus* and DUAP, and the ultimate objective of creating an operational system.

The environmental data in Clarus and DUAP are then discussed, and the report describes how the existing systems can be leveraged to develop an AERIS data environment based on the environmental data which are already defined and/or collected. This includes an overview of the user needs gathering process conducted with representatives from MARC and MDOT. Their broad needs were identified and discussed, specifically around transportation planning and transportation system management and operations, prior to identifying specific potential user applications.

The report then looks at the potential use of Clarus and DUAP environmental data elements as they could be applied to the Motor Vehicle Emissions Simulator (MOVES) environmental model and the VISSIM micro-simulation model. This provides a sense of the relevance of the existing Clarus and DUAP data sets, what changes might need to be made to existing data, such as their resolution, and what other data needs might be required to be added to the existing Clarus and DUAP data sets in an operational AERIS data environment.

Finally, the report lays out a Preliminary System Development Plan, which describes the process to migrate from the existing Clarus and DUAP systems to a new AERIS data environment. This discussion includes the steps for developing system concepts and user needs; requirements; system design; system development needs including core data management functions, data collection, data quality checking and pseudo-observation derivations, and data presentation and distribution; and testing and applications assessment.

3 BACKGROUND

The *Clarus* and DUAP systems represent the state-of-the-art in real-time data capture and management systems. As such, it is anticipated that many core components of these systems could be utilized to create an AERIS data environment compatible with other initiatives anticipated within the U.S. DOT DCM Program. It is important to note, however, that both the Clarus and DUAP systems underwent unique development processes focused on identifying and implementing the needs and requirements of their specific user communities. The needs of the AERIS user community must be expected to differ from those of Clarus and DUAP users, and so the systems requirements and their implementation through system design and development will likely deviate from the existing systems. A process for capturing and implementing these differences is described later in this report.

To help understand the potential differences that may arise, the following sections provide an overview of the existing Clarus and DUAP systems.

3.1 The Clarus System

Clarus is an initiative sponsored by U.S. DOT to acquire and manage environmental and road condition observation data to support four primary goals.

1. Provide a North American resource to collect, quality check, and make available surface transportation weather and road condition observations so that State Departments of Transportation (DOTs) and other transportation agencies can be more productive in maintaining safety and mobility on all roads and surface transportation platforms.
2. Surface transportation-based weather observations will enhance and extend the existing weather data sources that support general purpose weather forecasting for the protection of life and property.
3. Collection of real-time surface transportation-based weather observations will support real-time operational responses to weather.
4. Surface transportation-based weather observations integrated with existing observation data will permit broader support for the enhancement and creation of models that make better predictions in the atmospheric boundary layer and near the earth's surface to support more accurate forecasts.

The *Clarus* Initiative consists of two development components.

- The first component is the development of the *Clarus* System – a network for sharing, quality checking, and exchanging surface environmental data and relevant surface transportation conditions.
- The second component is the development of tools (such as decision support systems) that make effective use of the *Clarus* System.

The *Clarus* System collects, quality checks, and distributes surface weather and road condition observations and provides access to these data sets to state and local transportation agencies and value-added commercial weather service providers. The *Clarus* System hosts a variety of collector services that are responsible for collecting environmental observations from disparate sources. These collector services are easily configurable as the data sources—both stationary and mobile—are largely homogenous in their distribution and presentation processes; typically comma-separated-value or XML files retrieved from an FTP server. The quality checking algorithms applied to the environmental observations generally perform range, rate, duration, and neighbor evaluations, using an extensive collection of up-to-date sensor metadata. Combinations of quality checks enable the *Clarus* System to reasonably estimate if an observed environmental value is believable.

Clarus takes advantage of the substantial investments by state and local DOTs in Road Weather Information Systems (RWIS) that include Environmental Sensor Stations (ESS) to obtain atmospheric, surface, and subsurface weather observations for use in maintenance and operations activities. Most ESS are permanently fixed at sites throughout each state. More recently, however, the DOTs have started collecting mobile observations through deployment of sensors on their maintenance vehicles. The FHWA

Road Weather Management Program is currently working with the National Center for Atmospheric Research (NCAR) and the Minnesota and Nevada DOTs to acquire relevant meteorological data sets from snow plows. FHWA has directed expansions to the existing *Clarus* system to incorporate these mobile data sets as they become available.

NTCIP 1204: Environmental Sensor Station Interface Standard, Version 03, specifies air quality observations that may be acquired through either permanent or mobile ESS by state and local agencies. At this point in time, one *Clarus* data provider, the New Hampshire DOT, has equipped its ESS sites with environmental data sensors and has reported ozone observations to *Clarus*. This work has formed part of a research project between NHDOT and Plymouth State University.

Data from the *Clarus* System has a wide variety of direct and indirect uses. The following list identifies current users of the *Clarus* System:

- Owners of the observing systems including federal, state, local, and private institutions;
- Instrument and observation platform suppliers;
- The National Oceanic and Atmospheric Administration (NOAA);
- Specialist surface transportation weather service providers;
- General weather service providers;
- Research and engineering community; and
- Climate data warehouse and other non-surface weather interests.

During 2009, 314 unique users accessed data through the *Clarus* System (59,000+ hits). These users came from 19 countries and can be divided into the following categories:

- 62 government agencies (7 federal, 42 state, 13 local);
- 40 academic institutions;
- 17 value-added weather service providers;
- 2 TV stations;
- 30 other private sector firms;
- 163 unknown users.

In summary, the deployed *Clarus* System, www.clarus-system.com, includes:

- A web-based portal for accessing all surface transportation environmental observations;
- Data provided with and without post-processing, ready to be incorporated into value-added products including weather and traffic models, and decision support systems;
- Continuous quality checking of data for feedback to operators of the originating sensor stations and for use by the weather community to determine the validity of the observation;

- Ability to add new quality checking algorithms as they are developed;
- Data transferred in a single, common protocol with full metadata;
- Management of users' rights to input or extract specific data components;
- Data retrieval tools including on-demand requests and subscriptions; and
- Support for the inclusion of data sets from new sources as they become available, such as vehicle-based sensors, surface visibility information from traffic cameras, and remote sensing technologies.

3.2 The DUAP System

In 2006, MDOT was already an active participant in the Vehicle Infrastructure Integration (VII) program (referred to hereafter as the Connected Vehicle program) and was beginning to anticipate the impacts on agency operations of the data that would be generated by new connected vehicle sources. The broad purpose of the DUAP project was therefore to support MDOT and its local partner agencies in evaluating the uses and benefits of connected vehicle data, in combination with other data sources, such as Intelligent Transportation System (ITS) devices and traditional data collection programs, to enhance the management and operations of the transportation system.

The project focuses specifically on data uses and the benefits in responding to safety concerns, managing traffic, and managing MDOT's deployed assets. Four key outcomes were expected of the DUAP project:

- Identify potential uses for connected vehicle data, either individually or in combination with other data sources (e.g., speed, volume, and occupancy data from roadway sensors; meteorological observations from ESS) available to MDOT and its partners;
- Develop the required tools to manage, organize, and present the data;
- Develop techniques and specific algorithms to process the various data sets into applications that meet the needs identified by MDOT and other agency users; and
- Evaluate how well the developed tools, algorithms, and applications function in enhancing agency operations.

From the outset, the DUAP project envisioned the collection of data from multiple sources: the federal VII Proof-of-Concept Demonstration; a fleet of Chrysler-owned vehicles providing diagnostic data; ITS roadway and roadside sensors collecting data for traffic management and maintenance activities; and latterly a fleet of MDOT-owned vehicles equipped with data collection devices to fill identified gaps in the available data sets from other sources.

The system development process was based on these objectives and constraints. A core development challenge for the DUAP system was to gather data from multiple mobile platforms, where each source of data possesses its own data collection rates, formats, availability, and network transmission protocols. A modular design for the DUAP data collection component supports each different mobile data network, allowing them to be easily installed and immediately provide data as they become available.

The purpose of the collector services is to gather mobile data from disparate sources and translate those data into a common data storage format for processing. The collection processes for the DUAP system are complex. Every source of information is different in:

- Format (including XML, binary, binary-text, delta values);
- Content (i.e., every sensing platform has different observation types available in differing units);
- Data availability (e.g., 200 Hz, once per minute, once per five minutes, once per day); and
- Collection methods and protection mechanisms (including public-key, private-key, site-to-site VPN tunnel, address restriction, data volume, data signature, UDP binary, HTTP push and pull, FTP push and pull, and SMS).

From the perspective of the DUAP system, everything that is processed is effectively an "observation." An observation is defined as a numeric or string value associated with a time and space extent and a context. For example, the statement that "the measured air temperature in the foyer from noon to 1 PM was 68 degrees Fahrenheit" is a plain English version of an observation. Air temperature is the context, the foyer is a spatial extent (provided users have an agreed upon understanding of its relative location and size dimensions), noon to 1 PM is the time extent, and 68 degrees Fahrenheit is the recorded value. Everything the DUAP system collectors gather is reduced to this atomic observational unit.

Mobile data, once reduced to this common observation format, are also stored in this form. The DUAP system uses a MySQL database management system. However, traditional relational database software is too slow to stand up to the performance demands of the DUAP applications. The long-term storage and retrieval of mobile data is handled by flat files indexed by time and space and physically stored on parallel configured RAID for performance and redundancy purposes.

Much of the data processing is performed directly in hardware memory. Once mobile data are collected and converted to observations, the algorithms immediately process those data into other useful information. This may include generating derived observations from a set of measured observations, applying quality checks to the observations, or performing quick and simple operations to determine if a set of observations warrants being passed on to a more intensive analysis algorithm.

A series of user applications were also identified during the development of the DUAP Concept of Operations. Based on a preliminary understanding of the types of data that would be available through DUAP, the stakeholders identified candidate applications for development, including incident detection, queue length measurement, roadway segment travel time calculation, detection of road-weather conditions, and pavement condition monitoring and pothole detection. The initial phase of the DUAP project has emphasized the development of prototype applications (including those for visualization of traffic conditions on the network; link traffic speeds and travel times; and pavement condition monitoring). A second phase of the DUAP project will begin in June 2011 with a focus on moving applications into use by MDOT personnel.

These applications that have been developed through DUAP are enabled by the Michigan statewide geographic framework, which is an exhaustive meta-database of the state's transportation assets. These meta-data are critical in allowing the DUAP system to relate observed data in space to the context of the transportation infrastructure.

4 DEVELOPING AN AERIS DATA ENVIRONMENT

The preceding descriptions of the *Clarus* and DUAP systems can help illustrate the potential for creating a data environment for AERIS. Based on the development lessons from those systems, there are a number of compelling reasons for establishing an AERIS data environment. An AERIS data environment:

- Provides the ability to acquire environmental data sets from both fixed and mobile sources, and to store those data together with the associated metadata;
- Provides the ability to acquire and associate other, related data sets that provide context to the environmental data or support the development of applications;
- Provides the ability to perform a variety of quality checks on the environmental data and to make the results of the quality checks available to system users;
- Provides the ability to store and manage the acquired environmental data in a single location and to share it with other larger data acquisition and management systems, such as the proposed RDE;
- Provides the ability to process the data using appropriate algorithms to provide applications or enhanced data sets that meet user-defined needs, or to share the data with other systems through which external users can develop and implement their own applications;
- Provides the ability to manage access to the data or the resulting applications by users, including the provision of appropriate user rights management, data retrieval tools, and visualization tools.

These reasons are effectively the high-level system objectives that would help guide a preliminary system development approach described later in this report.

5 THE SYSTEMS DEVELOPMENT PROCESS

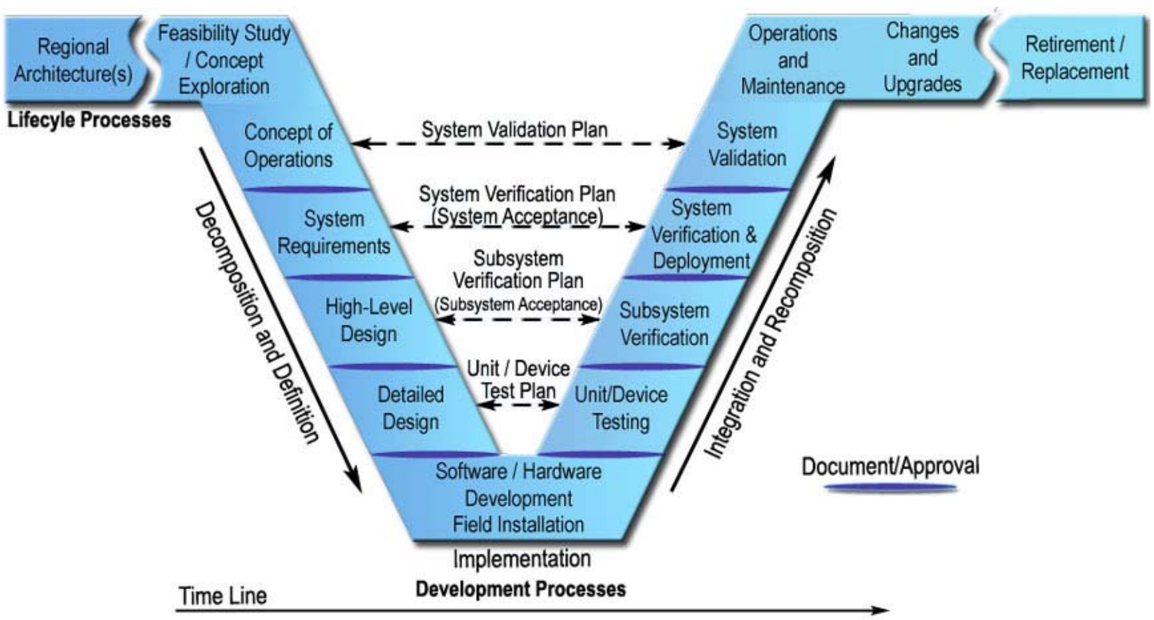
This report assumes that a discrete AERIS data environment would be desired as a repository for environmental data; allowing regional or potentially nationwide environmental data to be accessible to system developers, service providers, and other systems. In this assumed approach, the AERIS data environment would be one of many that would be accessed by the proposed RDE that will form the core of the U.S. DOT

DCM Program. In the event that a discrete AERIS data environment is established, this section briefly describes recommended system development practices.

The International Council of System Engineering (INCOSE) defines systems engineering as "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design and system validation while considering the complete lifecycle of the system." U.S. DOT has recognized the inherent value of systems engineering in transportation systems development and operations, to the extent that the use of a systems engineering process is a requirement of the National ITS Architecture Policy described in 23 CFR 940.11, which defines eligibility for federal ITS funding.

As a best practice, *every* project should follow a disciplined systems engineering process, from the beginning of planning through deployment and operations. It is highly recommended that the development of any ITS system be based on established IEEE and ANSI standards, consistent with U.S. DOT's expectations of systems engineering. The effectiveness of this approach results from a reliable process, based on those standards, with consistent stakeholder involvement and robust documentation. The process is nonetheless flexible, and can be adapted to suit ranges in project scope, complexity, and duration.

U.S. DOT has adopted a systems engineering that is illustrated by the "V-diagram" shown below:



In advance of the formal systems development process, there must be some concept of what is needed from the system, or what objectives must be met. For system developers, it is common to respond to a solicitation in which the procuring agency has laid out the need for a system and the scope of the development effort. In this project, the analysis of existing comparable systems and the preliminary stakeholder engagement help provide that initial conceptualization of an AERIS data environment. With that complete, a preliminary system development plan is presented in this report that follows the steps in the development process described below.

The typical systems engineering process begins with developing the **Concept of Operations**. The concept captures the stakeholders' essential needs for change and expectations of future capabilities, all based on a survey of the current situation. Expectations are captured in terms of both system features and operational scenarios. The process undertaken with the initial stakeholders in this project is prototypical of developing a complete concept of operations.

Development of **Requirements** is based on needs and expectations expressed in the Concept of Operations, expanded in dialogue with the stakeholders. Each area of need is expanded to finer levels of detail to capture the functions, capabilities, interfaces, rules, and constraints by which the system is expected to operate. Requirements may be developed through multiple iterations of detail with the system description, depending on the scope and complexity of the system.

At the highest level, the system is described by its **Architecture**. For ITS-based systems, the Architecture is essential both within the scope of the particular system development and as a connection to ITS capabilities in related projects. The Architecture should describe any changes to existing system components, new components yet to be developed, and interfaces to external systems. It becomes a parent description to the more detailed system design, and may develop iteratively with the Requirements.

The specifications for all the system components—hardware, software, communications, documentation—are developed in the **Design** process. This stage of the work may also involve the development of procurement documents that can be used to purchase, rather than develop, system components.

With detailed design complete, the project enters the system **Implementation** phase. During this stage, each of the elements of the design is built or purchased, tested, and integrated with other components.

Multiple iterations of **Testing** may be used as sets of components are integrated into a complete system. Verification and validation that the system meets its intended operational requirements culminates in system acceptance.

The system spends most of its life cycle in **Operations**, during which it must be monitored for continued compliance with its performance requirements and its configuration must be maintained. System parameters may need to be adjusted and refined to ensure the most efficient operation.

6 ENVIRONMENTAL DATA IN *CLARUS* AND DUAP

The *Clarus* and DUAP systems already have the ability to collect a variety of environmental data. As discussed earlier, any data acquired by these two systems is quality checked and stored for access by different users for various needs. Appendix B contains all of the data elements that can be collected from the *Clarus* and DUAP Systems. Table 1 below presents the environmentally-related data elements that are currently supported by either the *Clarus* or DUAP systems. The systems have been designed to collect all the data elements that are defined in NTCIP 1204, as well as additional data elements that are available from MDOT's probe vehicle fleet.

Once a data element is acquired by either of the two systems, it is not necessarily used by the system users. A "1" in the In Use column in Tables 1 and 2 indicates that at least one subscriber uses that particular data element.

Many of the data fields that are defined in the current systems are potentially relevant to AERIS applications. The most relevant of the existing data fields include information on location, wind, temperature, precipitation type and amount, surface conditions, atmospheric gas make-up, and engine performance including drive cycles and emissions. Since atmospheric data are not currently the focus of either the *Clarus* or DUAP systems, data fields that may be of greatest interest to AERIS (such as atmospheric gas make-up and engine performance) are defined but not used. These data fields can be populated once an appropriate source of these data is identified or created.

The modular design of the *Clarus* and DUAP systems also allows additional data elements to be acquired as new sources or new user needs are identified. Currently, for example, the potential for adding mobile source data to the *Clarus* System is being assessed. These data may include specialized data sets from agency winter maintenance vehicles such as snow plows (e.g., spreading rate, anti-icing chemical concentrations, etc.), and additional weather-related parameters from connected vehicles (e.g., windshield wiper status; traction control condition, etc.). The DUAP system will soon be supplemented with additional data from a new Michigan Vehicle-based Information and Data Acquisition System (VIDAS) fleet. These vehicles will be outfitted with additional sensors or data acquisition devices installed aftermarket by the research team to obtain the specific data elements needed for high-priority applications identified by MDOT users that are not otherwise easily obtained via the vehicle's onboard diagnostic port.

Table 1: *Clarus* and DUAP Environmental-Related Data Currently In-Use

Parameter Name	Parameter Description
essAtmosphericPressure	Force per unit area exerted by the atmosphere
windSensorAvgSpeed	Two-minute average of the wind speed
windSensorAvgDirection	Two-min. average of wind
windSensorSpotSpeed	Instantaneous wind speed
windSensorSpotDirection	Instantaneous wind
windSensorGustSpeed	Maximum wind gust during preceding 10 min.
windSensorGustDirection	Direction of max. wind gust preceding 10 min.
windSensorSituation	Wind from staffed stations only
essAirTemperature	Instantaneous dry-bulb temperature
essWetBulbTemp	Instantaneous wet-bulb temperature
essDewpointTemp	Instantaneous dewpoint temperature
essMaxTemp	Maximum air temperature preceding 24 hours
essMinTemp	Minimum air temperature preceding 24 hours
essRelativeHumidity	Relative humidity

essAdjacentSnowDepth	Depth of undrifted & unplowed snow off roadways
essRoadwaySnowDepth	Depth of unpacked snow on roadway surface
essRoadwaySnowpackDepth	Depth of packed snow on roadway surface
essPrecipYesNo	Precip detected: (1) precip; (2) noPrecip; (3) error
essPrecipRate	Rate of rainfall or water equivalent of snow
essSnowfallAccumRate	Rate of snowfall accumulation
essPrecipSituation	Precipitation type & intensity
essIceThickness	Thickness of the ice
essPrecipitationStartTime	Time when most recent precipitation event began
essPrecipitationEndTime	Time when most recent precipitation event ended
essPrecipitationOneHour	Total water equivalent over preceding 1 hr
essPrecipitationThreeHours	Total water equivalent over preceding 3 hrs
essPrecipitationSixHours	Total water equivalent over preceding 6 hrs
essPrecipitationTwelveHours	Total water equivalent over preceding 12 hrs
essPrecipitation24Hours	Total water equivalent over preceding 24 hrs
waterLevelSensorReading	Depth of the water from a user-defined point
essTotalSun	Total amount of sunshine during preceding 24 hrs
essTotalRadiation	Average total radiation during the radiation period
essVisibility	Surface visibility
essVisibilitySituation	Describes visibility of travel environment
essSurfaceStatus	Describes pavement surface status
essSurfaceTemperature	Current pavement surface temperature
essPavementTemperature	Current pavement temp. 2-10 cm below surface
essSurfaceSalinity	Pavement [surface] salinity
essSurfaceFreezePoint	Solution freeze point temperature
essSurfaceBlackIceSignal	Indicates whether or not black ice is detected
essPavementSensorError	Type of pavement sensor error
essSurfaceIceOrWaterDepth	Current ice thickness or water depth on roadway
essSurfaceConductivityV2	Conductivity of ice/liquid mixture on pavement
essSubSurfaceTemperature	Current sub-surface temperature
essSubSurfaceMoisture	Sub-surface moisture expressed as a percentage
icePercent	Percent of ice cover on roadway
precip10min	Total water equivalent over preceding 10 min
precipIntensity	Description of precipitation intensity
precipType	Description of precipitation type
essInstantaneousSolarRadiation	Instantaneous radiation hitting the earth's surface

7 GATHERING PRELIMINARY USER NEEDS

As described earlier, the process of gathering user needs is an essential step in the development of any new system. The scope of this project did not allow for the complete user needs gathering process that would be required to realize a fully-operational AERIS data environment. However, by engaging two strategic stakeholders – MARC, a metropolitan planning organization, and MDOT, a transportation system operating agency – the research team gained a good understanding of a range of user services and applications that could utilize enhanced environmental data, and consequently could envision at a conceptual level what an AERIS data environment would be required to do.

The research team approached the stakeholder engagement in a systematic way. The team undertook the following activities:

- Identified the available environmental data sets and other potentially relevant data elements that are acquired by or accommodated within Clarus and/or DUAP;
- Starting with the identified data sets, worked with MDOT and MARC to determine the relevance and value of these data to their program needs by assessing broad user service categories;
- In consultation with MDOT and MARC, examined the gaps and challenges in using the available data sets to fully satisfy existing needs, and identified potential uses of the data sets for specific new applications or performance measurement tools that would benefit from enhanced environmental data accessible through an AERIS data environment.

This initial identification of data elements serves two purposes in the research. First, it provides a discussion topic with the stakeholders; helping them to consider the types of data that may be relevant to their operational needs. Second, it provides some initial boundaries to the research. At this stage, it may not be productive to speculate about data elements that are desirable but totally outside the realm of possibility from these sources. As development of an AERIS data environment proceeds, further consideration can be given to the need for additional data sources that might potentially be provided through specialist sensors or collection techniques. As noted elsewhere, the addition of new data sources and observation types are easily accommodated in both *Clarus* and DUAP, and therefore can be considered a straightforward step in the AERIS data environment development process.

Once the available data elements were determined, as shown in Tables 1 and 2 above, the research team began to examine the uses to which the data could be applied by transportation professionals. The uses were broadly divided into four User Service categories: transportation planning; transportation system operations; transportation infrastructure management; and reporting. The purpose of this analysis was to further guide discussions with the project advisors and to help lay the framework for identifying how the data elements will support applications in the future. In turn, our understanding of the User Service categories and the User Applications help provide the initial conceptualization of an AERIS data environment that precedes the formal system development activities that define the acquisition, storage, processing, and dissemination techniques that must be applied to the data through the system.

To further facilitate review with the stakeholders, the four broad User Service categories were subdivided as follows to provide individual discussion topics:

- Transportation planning:
    - Potential use of data elements in emissions models, such as MOVES;
    - Potential use of data elements in traditional 4-step travel demand forecasting models;
    - Potential use of data elements in traffic simulation models at the microscopic, macroscopic, and mesoscopic levels;
- Transportation system operations:
    - Potential use of data elements in freeway, arterial, or corridor management;
    - Potential use of data elements in traffic control systems;
    - Potential use of data elements in active traffic and demand management;
- Transportation infrastructure management:
    - Potential use of data elements in asset management;
    - Potential use of data elements in infrastructure maintenance and maintenance management;
- Reporting:
    - Potential use of data elements in performance measurement;
    - Potential use of data elements in public outreach, awareness, and education.

Table 2 illustrates the responses of the stakeholders when questioned about the opportunities for using environmental data sets in each User Service category or subcategory. In general, the stakeholders expressed a belief that environmental data could serve a role in the majority of the User Service categories. In some instances, that role was envisioned as a direct input of higher volumes of better quality or higher resolution emissions data, such as providing enhanced data to the MOVES emissions model or having more up-to-date and specific data for air quality outreach and education initiatives. In other cases, the role was considered to be one of using these new sources of data to bring an environmental component to existing operational processes, such as the development of traffic management decision tools based on air quality impacts.

Table 2: Applicability of Data to User Service Categories

	User Service									
	Planning			Operations			Infrastructure		Reporting	
	Emissions Models	Travel Demand	Traffic Simul	Traffic Mgmt	Traffic Control	ATDM	Asset Mgmt	Maint Mgmt	Perform Meas	Outreach /Edu
Data Applicability	√	X	?	√	√	√	√	√	√	√

As shown in Table 3, only one subcategory completely failed to resonate with the stakeholders. They concluded that application of the data sets to traditional 4-step travel demand forecasting models will likely not have any direct relevance to environmental planning. However, the stakeholders did note that other connected vehicle information such as origin and destination data on a regional basis could certainly make those models more accurate. The stakeholders also expressed interest, but uncertainty of the role of environmental data sets in traffic simulation modeling. This topic was advanced for further analysis and is described later in this report.

As part of this discussion, the stakeholders also noted the importance of considering the required data resolution needed for the different data uses. For example, one use might rely on NOx readings aggregated on an hourly basis, while another might require these data on a minute-by-minute basis to be more closely aligned with a traffic signal cycle. These considerations must be explored in more detail as specific user applications are identified, and will directly influence the contributor, data acquisition, storage, processing, and dissemination requirements of the data capture and management systems.

Based on the potential data sets and the broad categories in which these data may be used, the user needs gathering focused on determining how the data could be used to develop or support various user applications. In this phase of the work, the research team held a workshop with MARC and MDOT personnel to discuss both the types of applications they currently use to make decisions, and other types of applications they might like to use if the necessary data sets and processing capabilities were available.

The stakeholders identified a series of potential applications that fell into three broad categories: applications that directly supported environmental and air quality programs; applications that could enhance some aspect of traffic management; and applications that could support the maintenance decisions of public agencies.

Environmental applications identified by the stakeholders included the use of relevant environmental data sets acquired from probe vehicles to influence the nature or timing of ozone and other air quality alerts that are issued to the public. The stakeholders also considered that environmental data sets could also be used to monitor public response to alerts and serve as input to public education programs relating to air quality initiatives. The stakeholders also identified the use of environmental data from probe vehicles as a potential input to eco-driving initiatives.

Traffic management applications described by the stakeholders included a broad set of objectives for smoothing traffic flows through both freeway and arterial management techniques. Specific techniques, such as “green waves” on signalized arterial streets could be optimized against environmental objectives such as emissions minimization. Active traffic and demand management techniques, such as ramp metering and variable speed limits, were viewed as having the potential to change vehicle emissions in real-time. The stakeholders also raised the idea of applying environmental metrics to various fleet management techniques for transit or commercial vehicles using environmental data sets derived from these vehicles.

An understanding of the key applications of interest to the stakeholders helps further define the system concept for an AERIS data environment from which formal system development can proceed.

Additional key topics emerged during the consultations with the stakeholders in relation to the development of applications using environmental data sets. These topics would again guide concept and system development tasks. In summary, these topics are:

- Appropriateness of the data sets – the data sets that can likely be derived from probe vehicles, including the environmental data sets, will be different to the data elements that are familiar to the users and that are used in current applications. What needs to be done to demonstrate that these new data sets will be appropriate for the identified applications?
- Sampling and sample size – At least initially, the amount of environmental data that can be derived from probe vehicles may be small. How will we be assured that a sufficient sample size is available for the various applications, particularly those that may need data acquired over a very small area such as the approach to a signalized intersection?
- Context of the data – Many of the identified applications may need data other than environmental data elements alone (e.g., an eco-driving application may need speed and volume data in addition to environmental parameters) and these data elements may be acquired from multiple different probe vehicles. How will data of different types and from disparate sources be assembled to maintain the context that is required for certain applications to function?

8 EXAMPLE ANALYSIS OF DATA REQUIREMENTS

To further examine how the environmental data elements identified in Table 1 may contribute to an individual model or application, two mature models used in planning and operational planning applications were investigated.

8.1 The MOVES Model

Transportation is a major consideration in terms of air quality, since it accounts for around 30 percent of total pollutant emissions. Transportation air quality planning refers to processes undertaken by transportation agencies to ensure conformity with federally-mandated air quality standards. This entails demonstrating that transportation projects and initiatives in areas of air quality concern do not exceed previously determined "emissions budgets." This is critical to transportation agencies since conforming to these regulations is required in order to obtain federal funding for transportation projects.

The U.S. Environmental Protection Agency (EPA) developed the MOVES model to be used for regional conformity determination, as well as project-level analyses. Therefore, the emissions estimates from the MOVES model play a central role in the air quality planning process. Information that can improve the accuracy of the inputs to the MOVES model (specifically those parameters reflecting the local conditions) is helpful and sometimes required by EPA for a valid and accurate air quality analysis. In this context, the *Clarus* and DUAP data elements that are identified in Table 1 can play a central role in improving the air quality planning process at different levels.

MOVES utilizes a database-centered software framework and a disaggregate emissions estimation algorithm that has much more flexibility for input and output options than the previous MOBILE6.2 model. This approach enables MOVES to perform estimation at different analysis levels, such as at the national, state, and local levels. New input options and changes in the way MOVES handles existing information require the users to create local information for an accurate analysis.

Users of the model specify vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and the road types being modeled. The MOVES model also incorporates estimates of energy consumption along with several coefficients including heating value, oxidization fraction, and carbon content. The model was designed to work with databases, allowing for new and updated data to be more easily incorporated into the model. The default database summarizes emissions information for the entire U.S. and is drawn from EPA research studies, Census Bureau vehicle surveys, FHWA travel data, and other federal, state, local, industry, and academic sources.

MOVES utilizes a disaggregate measure called Vehicle Specific Power (VSP), which is a combined measure of instantaneous speed, acceleration, road grade, and road load. Drive schedules that represent typical operations at different average speeds for each vehicle type operating on a road are used to translate average speed information into VSP distributions. The MOVES model is equipped with default drive cycles that are based on national level data. The emissions associated with any given driving pattern is modeled based on distribution of time spent in operation modal bins that are defined based on VSP bins and speeds. In addition to exhaust emissions, MOVES also provides estimates of start, brake wear, tire wear, and extended idling emissions.

In the MOVES model for each vehicle group, the running activities (i.e., non-start and non-idling) and associated emissions are organized into operating mode bins. The vehicle activity grouping is based on the instantaneous VSP and speed as shown in Table 3. Corresponding emissions rates for each of these bins are then used to calculate emissions for any driving pattern based on the distribution of time spent in the bins.

Table 3: Operating Mode Bin Definitions for Running Emissions.

Braking (Bin 0)			
Idle (Bin 1)			
VSP / Instantaneous Speed	**0-25 mph**	**25-50 mph**	**> 50 mph**
< 0 kW /tonne	Bin 11	Bin 21	
0 to 3	Bin 12	Bin 22	
3 to 6	Bin 13	Bin 23	
6 to 9	Bin 14	Bin 24	
9 to 12	Bin 15	Bin 25	
12 and greater	Bin 16		
12 to 18		Bin 27	Bin 37
18 to 24		Bin 28	Bin 38
24 to 30		Bin 29	Bin 39
30 and greater		Bin 30	Bin 40
60 to 12			Bin 35
< 6			Bin 33

The MOVES model uses fleet and vehicle activity data to estimate average emissions rates. Many of these data are calculated based on MOVES's baseline data and user inputs. For example, the default database for the most recent version of MOVES (MOVES2010) has two base years: 1990 and 1999. Other types of vehicle activity information are generated by modifying vehicle populations and applying appropriate correction factors and conversions.

To determine which elements of the *Clarus* and DUAP data sets can be used to enhance air quality analysis based on MOVES model a two step process is used. The first step was to identify the user inputs to the MOVES model for different levels of analyses. The second step was to determine which *Clarus* or DUAP data elements can be used to improve those inputs. The data elements were divided into three broad categories:

- Non useful - indicating that the data element is either not related to emissions estimation or is not deployed by MOVES analysis framework.
- Useful - indicating that the data element is either directly used by the MOVES model in the form of user inputs or with simple data processing it could be used to improve and update the inputs. In the latter case, appropriate methodologies are already established.
- Maybe useful - indicating that through more extensive data processing and analysis the data element can be used to improve and update the inputs or model assumptions. Usually, this process includes complex data analysis procedures.

The results of this analysis are presented in Table C1 in Appendix C.

8.2 The VISSIM Model

VISSIM is a leading micro-simulation traffic model developed and distributed by PTV America. It is frequently used for detailed modeling of freeway, arterial street, and transit applications. In addition to multi-modal traffic modeling, VISSIM also calculates vehicle emissions as part of the outputs through its emission module.

VISSIM uses vehicle emission files for the calculations. The file contents allow the specification of the vehicle emission characteristics and the relation between the emission components. There are twelve possible emission components: Benzene, CO, CO_2, HC, Fuel, NMOG, NMHC, NOx, Particulate, Soot, SO_2, and Evaporation. VISSIM uses two methods to estimate emissions: (i) users place nodes where they want to report emissions using VISSIM's internal equations; and (ii) users can define their own emissions model/algorithm. Emissions can be reported for each time step, for each vehicle (only in method ii), and for any location on the network.

Any relationships/equations developed between vehicle characteristics (e.g., speed, acceleration, fleet age, power, RPMs, engine temp, etc.) and the rate at which a specific emission component (e.g., CO2, NOx, etc.) is generated would be useful for microscopic simulation software. The micro-simulation software could use these relationships/equations to improve its ability to predict emissions under different scenarios. Consequently, better information could be incorporated into the decision making process. Therefore, any data elements from *Clarus* or DUAP that are shown to influence the rate of emissions would be useful.

Table C2 in Appendix C shows the results of this assessment. There are a small number of data elements that are definitely useful to modeling emissions in VISSIM/microscopic simulation models. Two data subcategories emerged under "maybe" useful: those that provide data about the atmosphere, and those that would support engine system modeling. Having more information about the influence of these data categories on emissions would be useful in determining how sensitive vehicle emissions are to the atmosphere or engine system performance compared to some of the more direct vehicle operational characteristics (e.g., speed, acceleration, deceleration). Consideration should be given to the atmosphere parameters being dynamically modeled (e.g., temperature change from 6 to 9 am) over the simulation period.

Many data elements in Table C2 are labeled with a "???" meaning it is unknown if they are useful. Some data elements are labeled as "dispersion" which may be an opportunity to interface traffic simulation software with other software models that simulate the atmospheric dispersion of mobile source emissions.

8.3 Other Models

While the previous sections specifically address the MOVES and VISSIM models, it is believed that the conclusions are applicable to other traffic and simulation models that summarize environmental data. However, many simulation models (especially macroscopic and mesoscopic models) do not attempt to quantify environmental data. For example, in the current Integrated Corridor Management (ICM) mesoscopic modeling effort being performed for U.S. DOT, the modeling evaluation team relied on MOBILE6 to post-process the environmental data based on the traffic output data from a mesoscopic model. Mesoscopic and macroscopic models can easily incorporate an emissions estimation module but it will be generally based on link- or regional-level outputs from some emissions model (e.g. MOVES, MOBILE6). Instead of post-processing, these models basically use a simplified version of emissions rates in the model.

Some of the microsimulation tools incorporate environmental outputs in their models. In the Synchro Model, the intersection performance outputs include fuel consumption (gal), CO emissions (kg), NOx emissions (kg), and VOC emissions (kg) by movement; these same statistics are also available for summary by intersection and for an entire arterial network. Intersection and network MOEs include fuel economy in mpg.

In the SimTraffic Model, the intersection performance outputs are very similar in terms of emissions outputs and include fuel used (gal), CO emissions (g), NOx emissions (g), and HC emissions (g) by movement; these same statistics are also available for summary by intersection and for an entire arterial network. Intersection and network MOEs include fuel efficiency in mpg.

9 PRELIMINARY SYSTEM DEVELOPMENT PLAN

As described earlier, the capabilities developed for and demonstrated by the *Clarus* and DUAP systems are directly applicable to an AERIS data environment. The use of these capabilities for environmental applications, however, would require development of new components outside the scope of those existing systems—user interfaces, data quality checking and processing algorithms, and collection schemes. The development process for these components that would be unique to an AERIS system should follow the systems engineering best practices to assure an efficient and effective implementation.

9.1 System Concepts and User Needs

The quality of the system concepts and completeness of user needs depends on extensive stakeholder involvement more than any other factor. The stakeholder team should include the sponsors, the system developers, and practitioners representing the entire field of potential system users. The *Clarus* and DUAP system development efforts used a variety of techniques for gathering user input, including structured workshops; task forces; brainstorming sessions; interviews; surveys or questionnaires; observation of existing work flows and systems; and observation of organizational interactions. These were supplemented with reviews of technical publications, descriptions of similar or related systems, constraints such as standards, legislative, and regulatory requirements, and any technological bounds that describe the state-of-the-art. Concepts and user needs for the *Clarus* System design, for example, were developed with FHWA, state and local DOTs, academia, associations, Environment Canada, and the private sector, including commercial weather information service providers and ESS vendors.

A similar process and stakeholder team would be appropriate and beneficial in developing the concepts and user needs for an AERIS data environment. The input gathered from MARC and MDOT in this study has been extremely valuable; expanding the range of stakeholders would provide entirely new perspectives. Candidate stakeholders include the AERIS program team, other state and local transportation and planning agencies; universities and research organizations; other federal agencies with interests in environmental data; and private sector data providers and users. This stakeholder team would then continue to be involved in an advisory role throughout the development and prototype phases of the system.

The resulting concepts and user needs would be documented in a Concept of Operations for an AERIS data environment. The document would build from the groundwork laid in this study to identify specific applications from the broader range of stakeholders; further develop the system concept; describe operational scenarios; and provide an overview of potential operations and policy impacts. Existing work in developing a Concept of Operations for the RDE within the U.S. DOT DCM Program could also be leveraged in this task.

9.2 Requirements

The system requirements describe what the system is to do. They formalize the user needs into a set of specific and testable statements about what functions are to be performed by the system and how it is to interface with its users and other systems. They will also describe the interaction of major system components, at least to the extent that such components are visible and separable within the overall system architecture. As such, the requirements become the basis for both the system design and for its testing.

Stakeholder involvement in requirements specification is critical to successful system development. The requirements become the system model for designers and developers. Individual stakeholders may have an interest in only some components of the system, but the aggregate effect of all stakeholders' input will be to describe a more complete and robust system. For AERIS, the diversity of stakeholders from data providers to system users will be very broad. Specific applications may put constraints on data gathering, quality checking, and synthesis that would be hard to discover without ongoing stakeholder interaction. Simulation and modeling applications, for example, may require particular data types, resolutions, and formats from the AERIS data environment. Operations-based applications may have particular data latency requirements that would affect the processing and dissemination of the data.

During the verification of requirements, the stakeholders would be engaged to review, comment, modify, add, or delete requirements to ensure a complete set of system requirements overall. The work product is a system requirements specification taken by designers and testers as the formal representation of the system intent.

9.3 System Design

The design process translates the requirements describing system functions (and constraints on those functions) into hardware and software objects that fulfill those functions. The preliminary design described in the concept of operations is evaluated against the requirements to confirm the essentials and identify any gaps. For the AERIS data environment, this process would assess the reuse and extension of capabilities in the *Clarus* and DUAP systems. For example, the eight modules within the *Clarus* System are strong candidates and would be evaluated for reuse, modification, or extension of capabilities. The *Clarus* System modules are as follows:

- Clarus (Clarus) - Clarus is the central package. It enforces an ordering and dynamically loads component observation processors through registration in the Clarus Manager. The CS and QEDS are dependent on this package for converting observation measurements to the appropriate units through the cache of units, and the unit converter.

- Collector Services (CS) - The CS Package receives and stores the environmental observation data from all sources. It sets up the collection process to run on a configured schedule. CS receives metadata from the EMC, and stores the observations in the QEDC.
- Environmental Metadata Cache (EMC) - The EMC retrieves metadata from the persistent database, stores environmental metadata about the contributors and collectors, and distributes environmental metadata.
- Environmental Metadata Services (EMS) - The EMS receives requests for environmental metadata and obtains the environmental metadata from the EMC. It writes out the environmental metadata to CSV files, and sends the formatted metadata to configured locations.
- Qualified Environmental Data Cache (QEDC) - The QEDC receives environmental data from the Clarus Manager, stores unqualified and qualified environmental data, and processes queries.
- Qualified Environmental Data Services (QEDS) - The QEDS Package handles the subscription requests to receive observation data. It obtains qualified environmental data from the QEDC and formats the data to fulfill the requests and subscriptions. QEDS sends the formatted environmental data back to the subscriber.
- Quality Checking Services (QChS) - The QChS receives unqualified environmental data from the Clarus Manager, executes multiple methods to quality check environmental data, applies quality flags, and sends the qualified environmental data back to the Clarus Manager queue for the next processor to handle.
- Utilities (Util) - The Util Package is composed of a wide variety of classes which are intended to provide functionality that can be used throughout the Clarus System. Many of the classes are meant to add convenience by having the ability to do some of the work required throughout the entire process.

Requirements for the AERIS data environment that are beyond the scope of those systems would be met through new components. Based on the material gathered in this preliminary study, new components are likely to be needed for data collection from the primary environmental data systems, including the collection of appropriate metadata; quality checking and algorithms for converting or deriving data from the primary observations; and generating reports, presentations, and output files for subsequent applications.

The design documentation provides a comprehensive view of the system. It should be written in a manner that makes the technical aspects of the design useful to the developers and accessible to the stakeholders. At a minimum, it contains a system deployment and hardware procurement view that includes descriptions of the system hardware components and the relationships between these components; a software view that includes the purposes and relationships between software modules; and a process view that describes the sample data sets to be processed by selected algorithms within specific applications.

9.4 System Development Needs

9.4.1 Core Data Management Functions

The core of the *Clarus* and DUAP systems consists of data management functions that index, store, and retrieve data for the external system interfaces and the modules that perform quality checks and other computations. Data structures and storage schemes support definition of new data types with a range of latency and bandwidth needs. All raw data are treated as “observations,” independent of their potential relationships to other data. This method allows tremendous flexibility and scalability in the growth of the data repository.

Data management functions also provide the means to associate the observations with metadata describing their sources and applications. These metadata associations add depth to the repository without compromising the scalability and performance of observation data storage and retrieval.

Implementing the AERIS data environment in a form similar to *Clarus* and DUAP would likely not require any significant changes to the core data management functions. Any additional development would be focused on additions to the observation data types and the metadata needed to support data collection, quality checking, and specific applications.

9.4.2 Data Collection

The requirements specification process will capture and document the diverse sources from which the AERIS data environment will be collecting data. Each data source will have its own data types, distribution formats, protocols, means of access (for example, by subscription or polling), and scheduling. Each such source or class of sources will then require its own collector service within the data environment. Experience with *Clarus* has demonstrated that even data sources running the same data logging systems may require unique collectors to accommodate differences in network access and scheduling.

An AERIS data environment implementation will require development of a collector for each of its data sources. Similar sources may use separate instances of a common collector, configured to their particular schedule or means of access.

9.4.3 Data Quality Checking and Pseudo-observation Derivations

Capture and management of field data observations is subject to a variety of uncertainties and variability. Furthermore, parameters of interest may not be directly observable, but need to be derived or inferred from other observations. In air quality applications, for example, individual vehicles are unlikely to support direct measurement of tailpipe emissions. Observations of vehicle behavior and performance across a fleet, however, could be used to infer aggregate air quality metrics. The *Clarus* and DUAP systems support these concerns through implementation of computational services for data quality checking and derivation of “pseudo-observations.”

The meteorological data collected by the *Clarus* System is subject to a variety of data quality checking algorithms. New algorithms have been added over time to introduce new quality checks appropriate to new data sets or to provide additional flexibility or enhanced sensitivity. These quality checks include:

- Sensor Range Test - Observation compared to manufacturer's published minimum and maximum values;
- Climate Range Test - Observation compared to historical climate minimum and maximum values per month by geographic area – gridded field;
- Step Test - Observation compared to previous observations over a configured time range to determine if the rate of change (plus or minus) is acceptable;
- Like Instrument Test - Observation compared to the same observation types from the same collection device;
- Persistence Test - Observation compared to previous observations to determine if the values had changed at all over a period of time;
- Spatial Tests - Observation compared to neighboring collection devices to determine if they are similar;
- Pseudo Observation Spatial Tests – Data are calculated for the initial collection location and neighboring collection locations from actual observations and then used in a spatial test.

The DUAP system has demonstrated a similar capability in generating "pseudo-observations" for particular applications where direct observations of certain parameters are not available. For example, the location of potential pavement defects—cracks and potholes—is inferred from observations of vehicle accelerations. Similarly, individual vehicle observations like speed, acceleration, and heading can be aggregated to estimate traffic flow measures, like speed, or to infer incident locations.

It is likely that an AERIS data environment would benefit from implementation of both quality checking and pseudo-observation algorithms. Methods used in the *Clarus* and DUAP systems could be re-used, modified, or extended. New methods particular to environmental data applications could be implemented within the existing framework.

For example, in those situations where roadside emissions monitors are used, existing *Clarus* quality checking procedures can be adapted to handle those data. In terms of the second-by-second data the following quality checks would be necessary:

- Time alignment between all data elements is a very important step because emissions data deal with multiple sources (i.e., emissions sensors, exhaust sensors, vehicle activity sensors (e.g., speed and acceleration)). The high variability in these data resulting from variability in driving conditions requires an accurate time alignment between the various data. Problems with inadequate time alignment will likely lead to significant errors in the application of the data.
- Sensor calibration is also important to data quality checking. Emission sensors are very sensitive devices and need to be precisely calibrated periodically. The calibration data need to be checked carefully to detect any drift in the readings.

Based on previous experience with emissions sensors, it is likely that the following specific tests will be required:

- Range Test - Observation compared to historical previous minimum and maximum values from similar vehicles;
- Persistence Test - Observation compared to previous observations of the same measurement run to determine if the values had changed over a period of time;
- Parallel Test – Observations are collected using two PEMS units and then the readings are compared to detect discrepancies.

9.4.4 Data Presentation and Distribution

The means of presenting and distributing data can be as important to the success of its application as the availability of the data itself. The system requirements specification process will have identified not only the characteristics of the data, but the conditions for and format of its outputs. The particulars of user interfaces and reports are notoriously difficult to elicit from the end users and to implement to their satisfaction.

Both the *Clarus* and DUAP systems provide a variety of user interfaces and reports. These generally fall into the following categories:

- Map-based presentations of data at a particular point in time, intended for browsing the data fields
- Standardized reports of particular sets of observations, generated at regular intervals, available by subscription or from an archive
- Ad hoc reports of limited scope for specific data lookup and retrieval

The particular presentation and distribution needs of the AERIS data environment applications would be determined in the requirements specifications.

9.5 Testing and Applications Assessment

Testing assures that the system has been properly implemented to meet the requirements and fulfill its intended applications. The process typically occurs at multiple levels, from the individual software and hardware units, to their integration within the system, and to the system's application to particular user scenarios. Code is reviewed and tested as modules are created, independent testers assess the completed system according to a specific test plan, and user acceptance tests provide a confirmation of functional intent.

The *Clarus* and DUAP systems have each undergone extensive review and testing from the development team, third-party reviewers, and clients. As an example, the DUAP system was used to collect, process, and present vehicle probe data for comparison with traditional pavement condition data. This application required unit testing of the data collectors and the processing algorithms, integration with the DUAP framework, and confirmation that data presentations were accurate. To validate the overall approach, MDOT vehicles were configured for both the traditional pavement profilometry methods and for collecting location, speed, and three-axis accelerometry data. This new technique for gathering pavement condition data creates new downstream opportunities to improve the efficiency and effectiveness of the DOT's operations.

Similar opportunities are likely to be created for transportation and environmental agencies through the AERIS data environment. Test plans should address applications of the data and baselining against existing data acquisition techniques, as well as the more fundamental unit and system testing.

APPENDIX A - DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly interpret this document.

Term	Definition
AERIS	Applications for the Environment: Real-Time Information Synthesis
ANSI	American National Standards Institute
ATDM	Active Traffic and Demand Management
BAA	Broad Agency Announcement
DCM	Data Capture and Management
DOT	Department of Transportation
DUAP	Data Use, Analysis and Processing
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
FTP	File Transfer Protocol
HTTP	Hypertext Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council of System Engineering
ITS	Intelligent Transportation Systems
MARC	Mid-America Regional Council
MDOT	Michigan Department of Transportation
MDSS	Maintenance Decision Support System
MODSS	Maintenance and Operations Decision Support System
MOVES	Motor Vehicle Emissions Simulator
NOAA	National Oceanographic and Atmospheric Administration
NOx	Nitrogen Oxides
NTCIP	National Transportation Communications for ITS Protocol
RAID	Redundant Array of Independent Disks
RDE	Research Data Environment
RWIS	Road Weather Information System
SMS	Short Message Service
TTI	Texas Transportation Institute
UDP	User Datagram Protocol
VII	Vehicle-Infrastructure Integration
XML	Extensible Markup Language

10 Appendix B – Data elements in the *Clarus* and DUAP systems

Clarus System Data

In Use	Parameter Name	Parameter Description
0	essLatitude	Latitude of the ESS station
0	essLongitude	East longitude from the Prime Meridian
0	essVehicleSpeed	Current speed being reported by the vehicle
0	essVehicleBearing	Current bearing of the vehicle
0	essVehicleOdometer	Current odometer reading of the vehicle
0	essReferenceHeight	Reference elevation of the ESS
1	essAtmosphericPressure	Force per unit area exerted by the atmosphere
1	windSensorAvgSpeed	Two-minute average of the wind speed
1	windSensorAvgDirection	Two-min. average of wind
1	windSensorSpotSpeed	Instantaneous wind speed
1	windSensorSpotDirection	Instantaneous wind
1	windSensorGustSpeed	Maximum wind gust during preceding 10 min.
1	windSensorGustDirection	Direction of max. wind gust preceding 10 min.
1	windSensorSituation	Wind from staffed stations only
1	essAirTemperature	Instantaneous dry-bulb temperature
1	essWetBulbTemp	Instantaneous wet-bulb temperature
1	essDewpointTemp	Instantaneous dewpoint temperature
1	essMaxTemp	Maximum air temperature preceding 24 hours
1	essMinTemp	Minimum air temperature preceding 24 hours
1	essRelativeHumidity	Relative humidity
1	essAdjacentSnowDepth	Depth of undrifted & unplowed snow off roadways
1	essRoadwaySnowDepth	Depth of unpacked snow on roadway surface
1	essRoadwaySnowpackDepth	Depth of packed snow on roadway surface
1	essPrecipYesNo	Precip detected: (1) precip; (2)

		noPrecip; (3) error
1	essPrecipRate	Rate of rainfall or water equivalent of snow
1	essSnowfallAccumRate	Rate of snowfall accumulation
1	essPrecipSituation	Precipitation type & intensity
1	essIceThickness	Thickness of the ice
1	essPrecipitationStartTime	Time when most recent precipitation event began
1	essPrecipitationEndTime	Time when most recent precipitation event ended
1	essPrecipitationOneHour	Total water equivalent over preceding 1 hr
1	essPrecipitationThreeHours	Total water equivalent over preceding 3 hrs
1	essPrecipitationSixHours	Total water equivalent over preceding 6 hrs
1	essPrecipitationTwelveHours	Total water equivalent over preceding 12 hrs
1	essPrecipitation24Hours	Total water equivalent over preceding 24 hrs
1	waterLevelSensorReading	Depth of the water from a user-defined point
1	essTotalSun	Total amount of sunshine during preceding 24 hrs
0	essCloudSituation	Description of amount of cloud cover
1	essTotalRadiation	Average total radiation during the radiation period
0	essTotalRadiationPeriod	Length of time essTotalRadiation is averaged
1	essVisibility	Surface visibility
1	essVisibilitySituation	Describes visibility of travel environment
1	essSurfaceStatus	Describes pavement surface status
1	essSurfaceTemperature	Current pavement surface temperature
1	essPavementTemperature	Current pavement temp. 2-10 cm below surface
1	essSurfaceSalinity	Pavement [surface] salinity
1	essSurfaceFreezePoint	Solution freeze point temperature
1	essSurfaceBlackIceSignal	Indicates whether or not black ice is detected
1	essPavementSensorError	Type of pavement sensor error
1	essSurfaceIceOrWaterDepth	Current ice thickness or water depth on roadway
1	essSurfaceConductivityV2	Conductivity of ice/liquid mixture on

		pavement
0	pavementSensorTemperatureDepth	Depth of the pavement temperature
1	essSubSurfaceTemperature	Current sub-surface temperature
1	essSubSurfaceMoisture	Sub-surface moisture expressed as a percentage
0	essSubSurfaceSensorError	Type of sensor error
0	essMobileFriction	Measured coefficient of friction
0	essMobileObservationGroundState	Prevailing observed ground state of environment
0	essMobileObservationPavement	Prevailing observed conditions on driving surface
0	essPaveTreatProductType	Type of treatment being applied to the road
0	essPaveTreatProductForm	Condition of treatment being applied to the road
0	essPercentProductMix	Percentage of the total application mix by weight
0	essPaveTreatmentAmount	Quantity of treatment being applied
0	essPaveTreatmentWidth	Width of the spread of treatment
0	essCO	Concentration of carbon monoxide in the air
0	essCO2	Concentration of carbon dioxide in the air
0	essNO	Concentration of nitrous oxide in the air
0	essNO2	Concentration of nitrous dioxide in the air
0	essSO2	Concentration of sulfur dioxide in the air
0	essO3	Concentration of ozone in the air

Michigan DOT DUAP System Data

In Use	Parameter Name	Parameter Description
1	icePercent	Percent of ice cover on roadway
1	precip10min	Total water equivalent precip. over preceding 10 min
1	precipIntensity	Description of precipitation intensity
1	precipType	Description of precipitation type
1	essInstantaneousSolarRadiation	Instantaneous radiation hitting the earth's surface
0	0100	PIDs supported [01 - 20]
0	0101	Monitor status
0	0102	Freeze DTC
0	0103	Fuel system status
0	0104	Calculated engine load
0	0105	Engine coolant temperature
0	0106	Short term fuel % trim Bank 1
0	0107	Long term fuel % trim Bank 1
0	0108	Short term fuel % trim Bank 2
0	0109	Long term fuel % trim Bank 2
0	010A	Fuel pressure
0	010B	Intake manifold absolute pressure
0	010C	Engine RPM
1	010D	Vehicle speed
0	010E	Timing advance
0	010F	Intake air temperature
0	0110	Mass air flow rate
0	0111	Throttle position
0	0112	Commanded secondary air status
0	0113	Oxygen sensors present
0	0114	Oxygen sensor voltage: Bank 1; Sensor 1
0	0115	Oxygen sensor voltage: Bank 1; Sensor 2
0	0116	Oxygen sensor voltage: Bank 1; Sensor 3
0	0117	Oxygen sensor voltage: Bank 1; Sensor 4
0	0118	Oxygen sensor voltage: Bank 2; Sensor 1
0	0119	Oxygen sensor voltage: Bank 2; Sensor 2
0	011A	Oxygen sensor voltage: Bank 2; Sensor 3
0	011B	Oxygen sensor voltage: Bank 2; Sensor 4
0	011C	OBD standards conformance
0	011D	Oxygen sensors present

0	011E	Auxiliary input status
0	011F	Run time since engine start
0	0120	PIDs supported [21 - 40]
0	0121	Distance traveled with MIL on
0	0122	Fuel rail pressure relative to manifold vacuum
0	0123	Fuel rail pressure diesel
0	0124	O2S1_WR_lambda
0	0125	O2S2_WR_lambda
0	0126	O2S3_WR_lambda
0	0127	O2S4_WR_lambda
0	0128	O2S5_WR_lambda
0	0129	O2S6_WR_lambda
0	012A	O2S7_WR_lambda
0	012B	O2S8_WR_lambda
0	012C	Commanded EGR
0	012D	EGR error
0	012E	Commanded evaporative purge
0	012F	Fuel level input
0	0130	Warm-up count since DTC cleared
0	0131	Distance traveled since DTC cleared
0	0132	Evaporative system vapor pressure
1	0133	Barometric pressure
0	0134	O2S1_WR_lambda
0	0135	O2S2_WR_lambda
0	0136	O2S3_WR_lambda
0	0137	O2S4_WR_lambda
0	0138	O2S5_WR_lambda
0	0139	O2S6_WR_lambda
0	013A	O2S7_WR_lambda
0	013B	O2S18_WR_lambda
0	013C	Catalyst temperature Bank 1 Sensor 1
0	013D	Catalyst temperature Bank 1 Sensor 2
0	013E	Catalyst temperature Bank 2 Sensor 1
0	013F	Catalyst temperature Bank 2 Sensor 2
0	0140	PIDs supported [41 - 60]
0	0141	Monitor status current drive cycle
0	0142	Control module voltage
0	0143	Absolute load value
0	0144	Command equivalence ratio
0	0145	Relative throttle position

1	0146	Ambient air temperature
0	0147	Absolute throttle position B
0	0148	Absolute throttle position C
0	0149	Accelerator pedal position D
0	014A	Accelerator pedal position E
0	014B	Accelerator pedal position F
0	014C	Commanded throttle actuator
0	014D	Time run with MIL on
0	014E	Time since trouble codes cleared
0	0151	Fuel type
0	0152	Ethanol fuel %
0	0153	Absolute evaporative system vapor pressure

11 Appendix C – ANALYSIS of C*larus* and *DUAP* data in MOVES and VISSIM

Parameter Name	Parameter Description	MOVES Useful	MOVES Maybe Useful	Comments on how, when, or why the data would be useful
essLatitude	Latitude of the ESS station (observation) per WGS-84 datum			
essLongitude	East longitude from the Prime Meridian of the ESS station (observation)			
essVehicleSpeed	Current speed being reported by the vehicle	x		Speed is a typical input to estimate emissions
essVehicleBearing	Current bearing of the vehicle			
essVehicleOdometer	Current odometer reading of the vehicle		x	currently is not directly used in MOVES. MOVES uses model year. Can be used to determin driving profile of a region
essReferenceHeight	Reference elevation of the ESS; height to base of station for permanent ESS; height to the ground su			
essAtmosphericPressure	Force per unit area exerted by the atmosphere	x		barometric pressure is used as an input
windSensorAvgSpeed	Two-minute average of the wind speed		x	if combined with vehicle and wind direction, it can be used to refine the drive cycles
windSensorAvgDirection	Two-min. average of wind direction (CW from North)		x	if combined with vehicle and wind direction, it can be used to refine the drive cycles
windSensorSpotSpeed	Instantaneous wind speed		x	if combined with vehicle and wind direction, it can be used to refine the drive cycles
windSensorSpotDirection	Instantaneous wind direction (CW from North)			
windSensorGustSpeed	Maximum wind gust recorded during preceding 10 min.			
windSensorGustDirection	Direction of max. wind gust during preceding 10 min.			
windSensorSituation	Describes the weather and travel situation in terms of wind from staffed stations only. Specific range			
essAirTemperature	Instantaneous dry bulb temperature		x	can be used to determine hourly/daily average temperature that can be input to MOVES
essWetBulbTemp	Instantaneous wet bulb temperature		x	can be used to determine hourly/daily average temperature that can be input to MOVES
essDewpointTemp	Instantaneous dewpoint temperature		x	can be used to determine hourly/daily humidity that can be input to MOVES
essMaxTemp	Maximum air temperature during preceding 24 hours		x	can be used to determine hourly/daily average temperature that can be input to MOVES
essMinTemp	Minimum air temperature during preceding 24 hours		x	can be used to determine hourly/daily average temperature that can be input to MOVES
essRelativeHumidity	Relative humidity	x		is used as an input (hourly)
essAdjacentSnowDepth	Depth of undrifted & unplowed snow off roadways			
essRoadwaySnowDepth	Depth of unpacked snow on roadway surface			
essRoadwaySnowpackDepth	Depth of packed snow on roadway surface			
essPrecipYesNo	Indicates whether or not precip is detected: (1) precip (2) no Precip (3) error			
essPrecipRate	Rate of rainfall or water equivalent of snow			
essSnowfallAccumRate	Rate of snowfall accumulation			
essPrecipSituation	Description of precipitation type & intensity; see NTCIP 1204 for validation rules and text mapping			
essIceThickness	Thickness of the ice			
essPrecipitationStartTime	Time when most recent precipitation event began			
essPrecipitationEndTime	Time when most recent precipitation event ended			
essPrecipitationOneHour	Total water equivalent precipitation over preceding 1 hr			
essPrecipitationThreeHours	Total water equivalent precipitation over preceding 3 hrs			
essPrecipitationSixHours	Total water equivalent precipitation over preceding 6 hrs			
essPrecipitationTwelveHours	Total water equivalent precipitation over preceding 12 hrs			
essPrecipitation24Hours	Total water equivalent precipitation over preceding 24 hrs			
waterLevelSensorReading	Depth of the water from a user-defined point			
essTotalSun	Total amount of sunshine during preceding 24 hrs			
essCloudSituation	Description of amount of cloud cover; see NTCIP 1204 for validation rules and text mapping			
essTotalRadiation	Average total radiation during the radiation period			
essTotalRadiationPeriod	Length of time essTotalRadiation is averaged (i.e., accumulated)			
essVisibility	Surface visibility			
essVisibilitySituation	Describes visibility of travel environment; see NTCIP 1204 for validation rules and text mapping			
essSurfaceStatus	Describes pavement surface status; see NTCIP 1204 for validation rules and text mapping			
essSurfaceTemperature	Current pavement surface temperature			
essPavementTemperature	Current pavement temp. 2-10 cm below surface, specifically at pavementSensorTemperatureDepth			
essSurfaceSalinity	Pavement (surface) salinity			
essSurfaceFreezePoint	Solution freezepoint temperature			
essSurfaceBlackIceSignal	Indicates whether or not black ice is detected; see NTCIP 1204 for data validation and mapping			
essPavementSensorError	Type of pavement sensor error; see NTCIP 1204 for data validation and mapping			
essSurfaceIceOrWaterDepth	Current ice thickness or water depth on roadway surface			
essSurfaceConductivityV2	Conductivity of the ice/liquid mixture on the pavement as detected by the sensor			
pavementSensorTemperatureDe	Depth at which the pavement temperature is detected			
essSubSurfaceTemperature	Current sub-surface temperature			
essSubSurfaceMoisture	Sub-surface moisture expressed as a percentage (e.g., 0 indicates dry, 100 indicates saturated)			
essSubSurfaceSensorError	Type of sensor error; see NTCIP 1204 for data validation and mapping			
essMobileFriction	Measured coefficient of friction		x	can be used to refine the VSP equation's parameters and drive cycles
essMobileObservationGroundSt	Prevailing observed ground state of the surrounding environment as determined by the observer; a			
essMobileObservationPavement	Prevailing observed conditions on the driving surface as determined by the observer; see NTCIP 120			
essPaveTreatProductType	Type of treatment being applied to the road; see NTCIP 1204 for data validation and mapping			
essPaveTreatProductForm	Condition of the treatment being applied to the road; see NTCIP 1204 for data validation and mappin			
essPercentProductMix	Percentage of the total application mix by weight that is of the type specified in essPaveTreatProdu			
essPaveTreatmentAmount	Quantity of the treatment being applied			
essPaveTreatmentWidth	Width of the spread of treatment			
essCO	Concentration of carbon monoxide in the air			
essCO2	Concentration of carbon dioxide in the air			
essNO	Concentration of nitrous oxide in the air			
essNO2	Concentration of nitrous dioxide in the air			
essSO2	Concentration of sulfur dioxide in the air			
essO3	Concentration of ozone in the air			

icePercent	Percent of ice cover on roadway			
precip10min	Total water equivalent precip. over preceding 10 min			
precipIntensity	Description of precipitation intensity			
precipType	Description of precipitation type			
essInstantaneousSolarRadiation	The instantaneous ultraviolet, visible, and near-infrared (wavelength of less than 3.0 micrometers) r			
0100	PIDs supported [01 - 20]			
0101	Monitor status			
0102	Freeze DTC			
0103	Fuel system status		x	can be used for evaporative emissions
0104	Calculated engine load		x	can be used for refining drive cycles and quality check of the results
0105	Engine coolant temperature			
0106	Short term fuel % trim Bank 1			
0107	Long term fuel% trim Bank 1			
0108	Short term fuel % trim Bank 2			
0109	Long term fuel% trim Bank 2			
010A	Fuel pressure			
010B	Intake manifold absolute pressure			
010C	Engine RPM		x	can be used for refining drive cycles and quality check of the results
010D	Vehicle speed	x		1Hz data can create custom/project level drive cycles - link-based data can determine av speed distribution by link type
010E	Timing advance			
010F	Intake air temperature			
0110	Mass air flow rate			
0111	Throttle position		x	can be used for refining drive cycles and quality check of the results
0112	Commanded secondary air status			
0113	Oxygen sensors present			
0114	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 1			
0115	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 2			
0116	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 3			
0117	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 4			
0118	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 1			
0119	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 2			
011A	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 3			
011B	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 4			
011C	OBD standards conformance			
011D	Oxygen sensors present			
011E	Auxiliary input status			
011F	Run time since engine start			
0120	PIDs supported [21 - 40]			
0121	Distance traveled with MIL on		?	
0122	Fuel rail pressure relative to manifold vacuum			
0123	Fuel rail pressure diesel			
0124	O2S1_WR_lambda			
0125	O2S2_WR_lambda			
0126	O2S3_WR_lambda			
0127	O2S4_WR_lambda			
0128	O2S5_WR_lambda			
0129	O2S6_WR_lambda			
012A	O2S7_WR_lambda			
012B	O2S8_WR_lambda			
012C	Commanded EGR		x	assuming that this indicates whether the vehicle has EGR or not; can be used to refine the vehicle distribution profile
012D	EGR error		x	assuming that this shows whether the vehicle has EGR or not; can be used to refine the vehicle distribution profile
012E	Commanded evaporative purge		x	can be used to refine evaporative emissions analysis
012F	Fuel level input			
0130	Warm-up count since DTC cleared			
0131	Distance traveled since DTC cleared			
0132	Evaporative system vapor pressure		x	can be used to refine evaporative emissions analysis
0133	Barometric pressure	x		is used as an input
0134	O2S1_WR_lambda			
0135	O2S2_WR_lambda			
0136	O2S3_WR_lambda			
0137	O2S4_WR_lambda			
0138	O2S5_WR_lambda			
0139	O2S6_WR_lambda			
013A	O2S7_WR_lambda			
013B	O2S18_WR_lambda			
013C	Catalyst temperature Bank 1 Sensor 1			
013D	Catalyst temperature Bank 1 Sensor 2			
013E	Catalyst temperature Bank 2 Sensor 1			
013F	Catalyst temperature Bank 2 Sensor 2			
0140	PIDs supported [41 - 60]			
0141	Monitor status current drive cycle			
0142	Control module voltage			
0145	Relative throttle position			
0146	Ambient air temperature	x		is used as an input (hourly)
0147	Absolute throttle position B			
0148	Absolute throttle position C			
0149	Accelerator pedal position D			
014A	Accelerator pedal position E			
014B	Accelerator pedal position F			
014C	Commanded throttle actuator			
014D	Time run with MIL on			
014E	Time since trouble codes cleared			
0151	Fuel type	x		is used as an input
0152	Ethanol fuel %	x		is used as an optional input to refine the fuel profile
0153	Absolute evaporative system vapor pressure		x	can be used to refine evaporative emissions analysis
status_v_wiper_front	Front Windshield Wiper Status			

Table B2 - Use of Environmental Data in VISSIM

		VISSIM		
Parameter Name	Parameter Description	Useful	Maybe Useful	Comments on how, when, or why the data would be useful
essLatitude	Latitude of the ESS station [observation] per WGS-84 datum			???
essLongitude	East longitude from the Prime Meridian of the ESS station [observation]			???
essVehicleSpeed	Current speed being reported by the vehicle	yes		Speed is a typical input to estimate emissions
essVehicleBearing	Current bearing of the vehicle			???
essVehicleOdometer	Current odometer reading of the vehicle	yes		Higher odo reading could infer higher emissions rate from reduced engine efficiency that comes with age/model
essReferenceHeight	Reference elevation of the ESS; height to base of station for permanent ESS height to the ground surface upon which t			???
essAtmosphericPressure	Force per unit area exerted by the atmosphere		maybe	atmosphere - if it influences the emissions output rate of a vehicle, dispersion factor as well
windSensorAvgSpeed	Two minute average of the wind speed			dispersion
windSensorAvgDirection	Two-min. average of wind direction (CW from North)			dispersion
windSensorSpotSpeed	Instantaneous wind speed			dispersion
windSensorSpotDirection	Instantaneous wind direction (CW from North)			dispersion
windSensorGustSpeed	Maximum wind gust recorded during preceding 10 min.			dispersion
windSensorGustDirection	Direction of max. wind gust during preceding 10 min.			dispersion
windSensorSituation	Describes the weather and travel situation in terms of wind from staffed stations only. Specific ranges for these values			dispersion
essAirTemperature	Instantaneous dry-bulb temperature		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essWetBulbTemp	Instantaneous wet-bulb temperature		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essDewpointTemp	Instantaneous dewpoint temperature		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essMaxTemp	Maximum air temperature during preceding 24 hours			dispersion
essMinTemp	Minimum air temperature during preceding 24 hours			dispersion
essRelativeHumidity	Relative humidity		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essAdjacentSnowDepth	Depth of undrifted & unplowed snow off roadways			???
essRoadwaySnowDepth	Depth of unpacked snow on roadway surface			???
essRoadwaySnowpackDepth	Depth of packed snow on roadway surface			???
essPrecipYesNo	Indicates whether or not precip is detected: (1) precip; (2) noPrecip; (3) error			??? Detecting precip or no precip does not seem useful in terms of emissions generation
essPrecipRate	Rate of rainfall or water equivalent of snow			dispersion
essSnowfallAccumRate	Rate of snowfall accumulation			???
essPrecipSituation	Description of precipitation type & intensity; see NTCIP 1204 for validation rules and text mapping			dispersion
essIceThickness	Thickness of the ice			???
essPrecipitationStartTime	Time when most recent precipitation event began			???
essPrecipitationEndTime	Time when most recent precipitation event ended			???
essPrecipitationOneHour	Total water equivalent precipitation over preceding 1 hr			???
essPrecipitationThreeHours	Total water equivalent precipitation over preceding 3 hrs			???
essPrecipitationSixHours	Total water equivalent precipitation over preceding 6 hrs			???
essPrecipitationTwelveHours	Total water equivalent precipitation over preceding 12 hrs			???
essPrecipitation24Hours	Total water equivalent precipitation over preceding 24 hrs			???
waterLevelSensorReading	Depth of the water from a user-defined point			???
essTotalSun	Total amount of sunshine during preceding 24 hrs			???
essCloudSituation	Description of amount of cloud cover; see NTCIP 1204 for validation rules and text mapping			???
essTotalRadiation	Average total radiation during the radiation period			???
essTotalRadiationPeriod	Length of time essTotalRadiation is averaged (i.e., accumulated)			???
essVisibility	Surface visibility			???
essVisibilitySituation	Describes visibility of travel environment; see NTCIP 1204 for validation rules and text mapping			???
essSurfaceStatus	Describes pavement surface status; see NTCIP 1204 for validation rules and text mapping			???
essSurfaceTemperature	Current pavement surface temperature			???
essPavementTemperature	Current pavement temp. 2-10 cm below surface, specifically at pavementSensorTemperatureDepth			???
essSurfaceSalinity	Pavement [surface] salinity			???
essSurfaceFreezePoint	Solution freeze point temperature			???
essSurfaceBlackIceSignal	Indicates whether or not black ice is detected; see NTCIP 1204 for data validation and mapping			???
essPavementSensorError	Type of pavement sensor error; see NTCIP 1204 for data validation and mapping			???
essSurfaceIceOrWaterDepth	Current ice thickness or water depth on roadway surface			???
essSurfaceConductivityV2	Conductivity of the ice/liquid mixture on the pavement as detected by the sensor			???
pavementSensorTemperature	Depth at which the pavement temperature is detected			???
essSubSurfaceTemperature	Current sub-surface temperature			???
essSubSurfaceMoisture	Sub-surface moisture expressed as a percentage (e.g., 0 indicates dry, 100 indicates saturated)			???
essSubSurfaceSensorError	Type of sensor error; see NTCIP 1204 for data validation and mapping			???
essMobileFriction	Measured coefficient of friction			???
essMobileObservationGround	Prevailing observed ground state of the surrounding environment as determined by the observer; an indicator of past			???
essMobileObservationPaveme	Prevailing observed conditions on the driving surface as determined by the observer; see NTCIP 1204 for data validatio			???
essPaveTreatProductType	Type of treatment being applied to the road; see NTCIP 1204 for data validation and mapping			???
essPaveTreatProductForm	Condition of the treatment being applied to the road; see NTCIP 1204 for data validation and mapping			???
essPercentProductMix	Percentage of the total application mix by weight that is of the type specified in essPaveTreatProductType			???
essPaveTreatmentAmount	Quantity of the treatment being applied			???
essPaveTreatmentWidth	Width of the spread of treatment			???
essCO	Concentration of carbon monoxide in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists

essCO2	Concentration of carbon dioxide in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essNO	Concentration of nitrous oxide in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essNO2	Concentration of nitrous dioxide in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essSO2	Concentration of sulfur dioxide in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
essO3	Concentration of ozone in the air		maybe	atmosphere - if it influences the emissions output rate of a vehicle/if research shows a relationship exists
icePercent	Percent of ice cover on roadway			???
precip10min	Total water equivalent precip. over preceding 10 min			dispersion
precipIntensity	Description of precipitation intensity			dispersion
precipType	Description of precipitation type			dispersion
essInstantaneousSolarRadiati	The instantaneous ultraviolet, visible, and near-infrared (wavelength of less than 3.0 micrometers) radiation hitting th			???
0100	PIDs supported [01 - 20]			
0101	Monitor status			
0102	Freeze DTC			
0103	Fuel system status		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0104	Calculated engine load		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0105	Engine coolant temperature		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0106	Short term fuel % trim Bank 1			
0107	Long term fuel % trim Bank 1			
0108	Short term fuel % trim Bank 2			
0109	Long term fuel % trim Bank 2			
010A	Fuel pressure		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
010B	Intake manifold absolute pressure		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
010C	Engine RPM	yes		may be able to indirectly estimate this from engine type, speed, acceleration
010D	Vehicle speed	yes		speed is a typical input to estimate emissions
010E	Timing advance		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
010F	Intake air temperature		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0110	Mass air flow rate		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0111	Throttle position		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0112	Commanded secondary air status		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0113	Oxygen sensors present			??? I don't believe its presence alone influences emissions
0114	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 1		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0115	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 2		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0116	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 3		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0117	Oxygen sensor voltage: Short term fuel trim Bank 1 Sensor 4		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0118	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 1		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0119	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 2		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
011A	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 3		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
011B	Oxygen sensor voltage: Short term fuel trim Bank 2 Sensor 4		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
011C	OBD standards conformance			??? not sure if conformance is a factor
011D	Oxygen sensors present			??? I don't believe its presence alone influences emissions
011E	Auxiliary input status			???
011F	Run time since engine start	yes		Engine temp influences emission rates/code needed to model engine temp
0120	PIDs supported [21 - 40]			
0121	Distance traveled with MIL on			
0122	Fuel rail pressure relative to manifold vacuum		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0123	Fuel rail pressure diesel		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0124	O2S1_WR_lambda			
0125	O2S2_WR_lambda			
0126	O2S3_WR_lambda			
0127	O2S4_WR_lambda			
0128	O2S5_WR_lambda			
0129	O2S6_WR_lambda			
012A	O2S7_WR_lambda			
012B	O2S8_WR_lambda			
012C	Commanded EGR			
012D	EGR error			
012E	Commanded evaporative purge		maybe	if it influences the emissions output rate of a vehicle
012F	Fuel level input		maybe	if it influences the emissions output rate of a vehicle
0130	Warm-up count since DTC cleared		maybe	if it influences the emissions output rate of a vehicle
0131	Distance traveled since DTC cleared		maybe	if it influences the emissions output rate of a vehicle
0132	Evaporative system vapor pressure		maybe	if it influences the emissions output rate of a vehicle
0133	Barometric pressure		maybe	atmosphere - if it influences the emissions output rate of a vehicle
0134	O2S1_WR_lambda			
0135	O2S2_WR_lambda			
0136	O2S3_WR_lambda			
0137	O2S4_WR_lambda			
0138	O2S5_WR_lambda			
0139	O2S6_WR_lambda			
013A	O2S7_WR_lambda			
013B	O2S18_WR_lambda			
013C	Catalyst temperature Bank 1 Sensor 2		maybe	if it influences the emissions output rate of a vehicle
013E	Catalyst temperature Bank 2 Sensor 1		maybe	if it influences the emissions output rate of a vehicle
013F	Catalyst temperature Bank 2 Sensor 2		maybe	if it influences the emissions output rate of a vehicle
0140	PIDs supported [41 - 60]			
0141	Monitor status current drive cycle	yes		drive cycle is a VISSIM output which could be used in real time or post processed to estimate emissions
0142	Control module voltage		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0143	Absolute load value		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0144	Command equivalence ratio		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0145	Relative throttle position		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0146	Ambient air temperature		maybe	atmosphere - if it influences the emissions output rate of a vehicle
0147	Absolute throttle position B		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0148	Absolute throttle position C		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
0149	Accelerator pedal position D		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
014A	Accelerator pedal position E		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
014B	Accelerator pedal position F		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
014C	Commanded throttle actuator		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
014D	Time run with MIL on			not sure what MIL is
014E	Time since trouble codes cleared			???
0151	Fuel type	yes		diff fuel types have diff emission characteristics. An input where each fuel type reflects a certain vehicle type
0152	Ethanol fuel %	yes		diff fuel types have diff emission characteristics. An input where each fuel type reflects a certain vehicle type
0153	Absolute evaporative system vapor pressure		maybe	engine system modeling - if it influences the emissions output rate of a vehicle
status_v_wiper_front	Front Windshield Wiper Status			no

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